Mechanical Metrology for Small-Scale Structures

Industrial trends toward miniaturization require quantitative mechanical property data for design, development, and fabrication of modern small-scale devices. Developments in disruptive technologies require engineering materials data for structures and architectures at multiple (nano to macro) length scales. Accordingly, we are designing and developing mechanical testing configurations from small-scale in-situ *structures for localized measurements of fracture and deformation behavior of materials and interfaces.*

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This project aims to: (i) measure mechanical properties of microstructures for myriad industrial and biological systems that cannot be fabricated in bulk samples; (ii) study small-scale phenomena, which may be controlled by surface effects (*e.g.*, the influence of surface stresses on crack nucleation and extension); and (iii) obtain quantitative mechanical property data of materials and interfaces for designing small-scale structures and components and for assessing their mechanical reliability. Well-characterized testing configurations are being designed and developed for measurements of strength and crack extension of small-scale structures and interfaces. We are pursuing four tasks: (i) configuration design, optimization, and characterization via finite-element analyses; (ii) specimen fabrication; (iii) mechanical testing and fracture analysis (fractography); and (iv) length and force metrology. In addition to work in the Ceramics Division (tasks i, iii, and iv), two collaborations were established in the fabrication task (ii): one with James A. Beall of the Quantum Electrical Metrology Division in NIST Boulder, and one with Northwestern University.

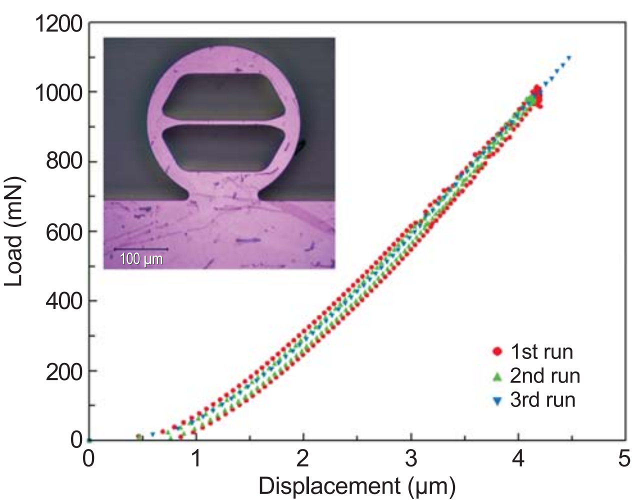

Figure 1: Repeatability for multiple loading of a single specimen.

Significant progress has been made in the design of a compressively loaded test configuration with a well-defined, tensile gage section. The inset of Figure 1 shows one such specimen fabricated by James Beall using deep reactive ion etching (DRIE) of a silicon wafer. When a load is applied to the top of this theta-like geometry, a uniform uniaxial tensile stress develops in the middle gauge section. Finite element analysis gives (horizontal) gauge section stress and strain as functions of the applied load and load-point displacement, respectively. Dimensionless calibration factors have been obtained for several specimen and fillet geometries, and as a function of the gauge width.

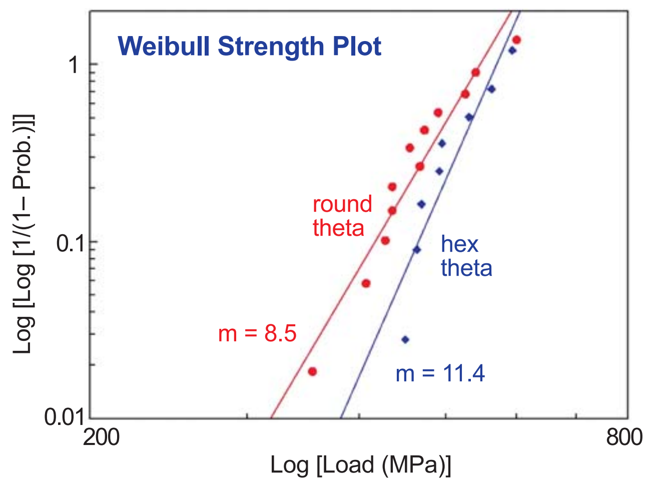

Figure 2: Weibull plots for round and hexagonal configurations.

Specimens are tested using a depth-sensing nanoindenter as a universal testing machine, thereby giving a continuous record of applied load and load-point displacement. Repeatability is illustrated in Figure 1. Strength data for DRIE silicon, Figure 2, suggest that differences for round and hexagonal specimen configurations are not significant.

To extend this technique to a wider variety of material systems, focused-ion-beam (FIB) milling is being explored in collaboration with Northwestern University. Hexagonal theta specimens fabricated from a lamellar directionally solidified eutectic of $Ni_{0.5}Co_{0.5}O$ and ZrO_2 are approximately 1/15 the size of the silicon specimens.

Contributors and Collaborators

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